OBSERVATION OF BEAM LOSS PROTON TRACKS AT 400 MEV J-PARC LINAC

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Abstract

In J-PARC Linac, from ACS (Annular-Coupled Structure linac) to L3BT (Linac to 3-GeV Beam Transport) sections, highest beam loss was observed. This beam loss is considered to be caused mainly by H^0 generated by ionization of H^- by residual gas in the beam duct. The H^0 is further changed to H^+ when penetrating the beam duct. We have developed a detector system consisting of 8 planes of scintillating fiber hodoscopes. Each hodoscope consists of 16 fibers of 4x4 mm^2 square or 4 mm diameter circle cross sections with 64 mm length. The upstream detector (4 planes) is separated from the downstream detector (4 planes) by about 1.2 m to measure time-of-flight of charged particles. Each detector can move in horizontal and vertical directions with stepping motors. We observed proton tracks due to beam loss for the first time at 400 MeV from April to June of 2017.

INTRODUCTION

We measure tracks of H^+ (protons) originated from the H^0 produced inside the beam duct between QM02 and QM03 of L3BT section using the scintillating fiber hodoscope system. For detailed description of the detector system, refer to Refs. [1-5]. The paper reports first measurements of H^+ tracks after the 400 MeV upgrade of J-PARC Linac.

We measure energy of the protons with the time-of-flight between the upstream detector and the downstream detector, which are separated by 1.2 m in the z (beam axis) direction. Each detector system consists of two fiber planes to measure horizontal positions and two planes to measure vertical planes. We define the plane from upstream to downstream as (H0, H1, V0, V1, H2, H3, V2, V3), where signals of V3 are not read out due to the limitation of number of electronics channels. The upstream and downstream detectors can move independently in the horizontal and vertical directions.

We search for a straight track both in the x-z projection, in the y-z projection, and also in the t-z projection, where x is horizontal, y is vertical, and z is along the beam axis, and t is the time. We require hits in all the 7 planes (H0-H3 and V0-V2) and apply cuts in the residuals and χ^2 of the straight-line fit of the track.

EXPERIMENTAL SETUP

We performed measurements from April to June in 2017. The upstream and downstream fiber detectors are positioned at the beam height, and horizontal positions are set to 373 mm and 499 mm, respectively, with respect to the beam center.

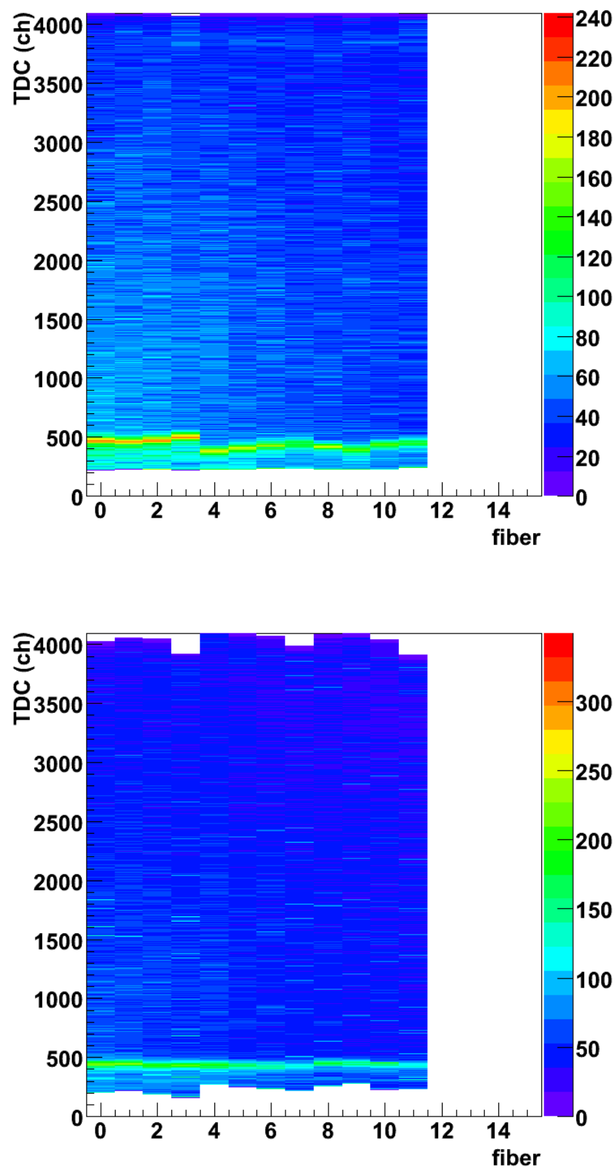

Figure 1: TDC distributions (ch) for each fiber in Plane H1 before (top) and after (bottom) the timing calibration.

We utilized final-stage dynode signals (DY) which are available for the Hamamatsu photomultiplier H8500C. The DY signals are opposite polarity (positive) signals to the negative anode signals. Since the photomultiplier (PMT) is a multi-anode PMT, the DY signal serves as analog sum signal over all anode channels. We discriminate the DY signals of the four PMT's (DY1 for H0/H1, DY2 for V0/V1, DY3 for H2/H3, and DY4 for V2), and form coincidence

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signal of discriminated DY1, DY2, DY3, and DY4 for the start timing of TDC's and the timing gate of QDC's. We also formed a time gate (TG) from the scheduled beam start timing to define the timing within the macro pulse. The coincidence DY1&DY2&DY3&DY4&TG is used for the data taking. In this experiment, we defined TG as the first medium bunch (first 100 ns of the macro pulse).

We performed the timing calibration of the timing measurement system in July 2017. We generated pulses using a function generator for the trigger (positive pulse) and the PMT signals (negative pulse) at the same timing. The latter was delayed by the fixed delay time and injected to a FAN-OUT module, and output signals are injected to coaxial cables of PMTs. The former signal was injected to one of the dynode signal cables which is used to form the trigger. The same data acquisition system for the fiber measurements was used to measure signal timings using TDCs. Time zeros and time intervals for each TDC channel (ch/ns) were measured and used to correct for each TDC channel. The TDC distributions at each fiber in H1 plane before and after the timing calibration are shown in Fig. 1. After the calibration, peak positions due to protons are aligned.

We also corrected for the difference in the timing of the TDC start signals among three TDCs.

RESULTS

For track reconstruction, we require 6- or 7-plane hits out of 7 planes. We applied cuts in χ^2 of straight-line fits of x-z, y-z, and t-z tracks. We first checked if the hits on each fiber plane is aligned as straight charge particle tracks. Fig. 2 shows residuals of the x-position (mm) and the time (ns) of fiber hits with respect to fitted tracks at Plane H2. A sharp single peak is observed, which is the evidence for straight charge particle tracks. We applied also track matching cuts on inner planes (H1, V1, and H2) in x-t or y-t planes.

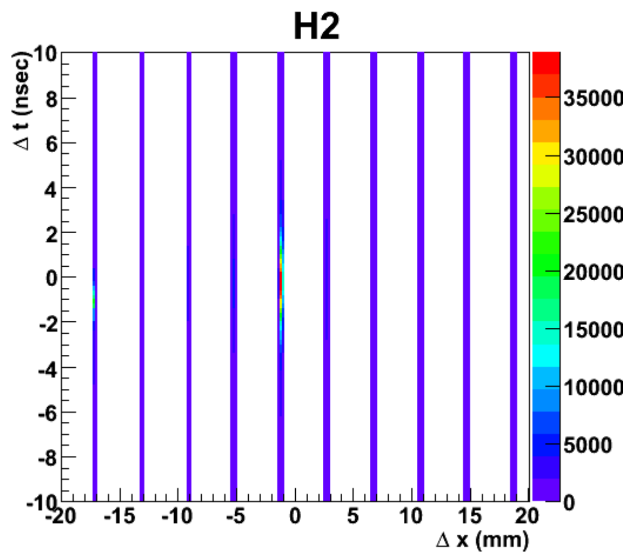

Figure 2: Residuals of x (mm) and time (ns) of fiber hits with respect to fitted tracks at Plane H2.

Then, we estimated the timing resolution at Plane V1 by using the width of the residuals of the hit time with respect to the fitted z-t track as shown in Fig. 3. The estimated timing resolution is 1.148±0.004 ns in this plane.

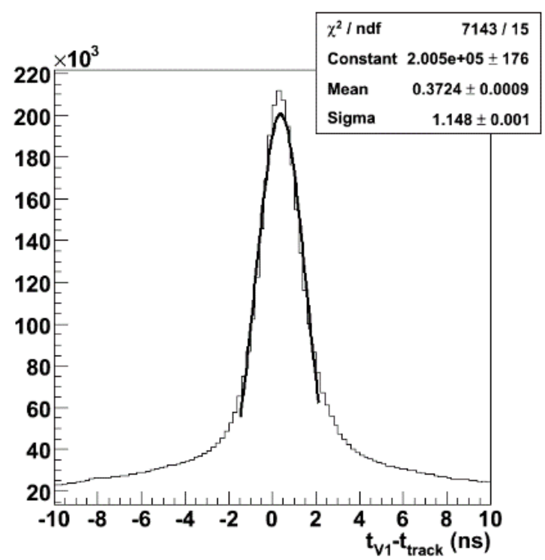

Figure 3: Residuals of time (ns) of the fiber hit with respect to the fitted track at Plane V1.

The resulting time-of-flight distribution of H0-V2 pair is shown in Fig. 4. The distribution consists of accidental background (green line), and the signal for charged tracks (blue line). The distribution is fit with a combined function of a Gaussian function for the background and a Lorentzian function for the signal as shown in the red line.

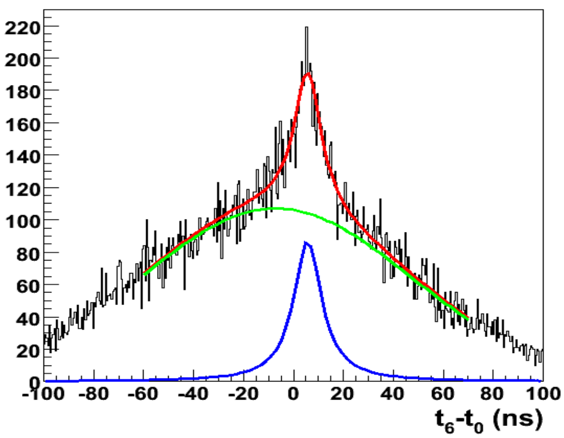

Figure 4: The preliminary distribution of the time-of-flight (ns) between Planes H0 and V2. The distribution is fitted with a combined function (red) between a Gaussian function for the background (green) and a Lorentzian function for the signal (blue).

The result is shown in Table 1. The measured time-of-flight is 5.71±0.30 ns, corresponding to β=0.72±0.04 with the flight length of 1231 mm. Assuming the proton, the kinetic energy is calculated to be 413^{+91}_{-66} MeV. Since there should be some beam loss when H^- passes through the beam pipe, the measured energy seems to be higher than the H^- beam energy of 400 MeV. The measured charged tracks are most probably protons. We require more detailed systematic studies such as geometry, timing in the electronics to improve the precision. We also need comparison with detailed simulation.

Table 1: Preliminary results with the H0-V1 plane pair for the time of flight (TOF), the path length (L), the velocity (β), and the kinetic energy (W).

θ_x (deg)	7.0±0.4
TOF (ns)	5.71±0.30
L (mm)	1231
β	0.72±0.04
W (MeV)	413^{+91}_{-66}

CONCLUSION

We performed measurements of charged particle trajectories using the fiber hodoscope system. We observed proton tracks for the first time after 400-MeV upgrade of J-PARC Linac. The measured particle energy was 413^{+91}_{-66} MeV, which is higher than proton energy from 400-MeV H^- beam. We are going to perform more detailed studies to improve energy precisions, and also we will measure H^- beam loss rates with various detector angles in near future.

REFERENCES

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